TABLE 1

Refrigeration Loads:

Ckt.	Description	Load [Btu/Hr]	% Load of Total	Case Mass Flow based on Recirc=2		
1	Island Freezer	5,600	21.1%	86 lb/hr =	0.161	Gpm
2	Reach-In I.C. Case	4,800	18.0%	74 lb/hr =	0.138	Gpm
3	Reach-In F.F. Case	4,200	15.8%	65 lb/hr =	0.121	Gpm
4	8'x8'x8' Walk-In I.C. Freezer	6,000	22.6%	93 lb/hr =	0.173	Gpm
5	8'x8'x8' Walk-In F.F. Freezer	6,000	22.6%	93 lb/hr =	0.173	Gpm
		Total 26,600	100%			

CO_2 (R-744) Properties at -20°F

$P_{saturation}$	=	214.9	[Psia]
	or	200.2	[Psig]
h_{liquid}	=	9.78	[Btu/Lb]
h_{vapor}	=	139.4	[Btu/Lb]
$h_{vaporization}$	=	129.6	[Btu/Lb]
ρ_{liquid}	=	66.86	[Lb/Ft³]
ρ_{vapor}	=	2.41	[Lb/Ft³]
$c_{p,liquid}$	=	0.4975	[Btu/Lb°F]
$c_{p,vapor}$	=	0.2760	[Btu/Lb°F]

R-507 Properties for DX Evaporator

$P_{saturation}$	=	32.7	[Psia]
	or	18.0	[Psig]
h_{liquid} @ 50°F	=	28.37	[Btu/Lb]
h_{vapor} @ -20°F	=	85.07	[Btu/Lb]
$h_{refrigeration\ effect}$	=	56.70	[Btu/Lb]
ρ_{liquid} @ 50°F	=	69.67	[Lb/Ft³]
ρ_{vapor} @ -20°F	=	0.7444	[Lb/Ft³]
$c_{p,liquid}$ @ -20°F	=	0.3027	[Btu/Lb°F]
$c_{p,vapor}$ @ -20°F	=	0.2052	[Btu/Lb°F]

If saturated liquid entering and saturated vapor leaving evaporator:

Mass flow rate	=	205.2	[Lb/Hr]
	or	3.421	[Lb/Min]
Liquid Volume Flow	=	0.0512	[Ft³/Min]
	or	0.383	[Gpm]
Vapor Volume Flow	=	1.419	[Ft³/Min]
	or	10.62	[Gpm]

Mass flow rate	=	469.2	[Lb/Hr]
	or	7.820	[Lb/Min]
Liquid Volume Flow	=	0.1122	[Ft³/Min]
	or	0.840	[Gpm]
Vapor Volume Flow	=	10.505	[Ft³/Min]
	or	78.58	[Gpm]

To maintain 120 [Ft/Min] in Liquid Line:

CO_2 Equiv. Line Size =	0.28	[In Ø]
R-507 Eqiv. Line Size =	0.41	[In Ø]

To maintain 1300 [Ft/Min] in Suction Line:

CO_2 Equiv. Line Size =	0.45	[In Ø]
R-507 Eqiv. Line Size =	1.22	[In Ø]

With a 1.5 circulation Rate:

CO_2 Equiv. Liquid Line Size	=	0.34	[In Ø]
CO_2 Equiv. Vapor Line Size	=	0.63	[In Ø]

We will Install:

CO_2 Liquid Line Size	=	1/2	[In ID]
CO_2 Vapor Line Size	=	7/8	[In ID]

Secondary Coolant Line Sizing

Refrigeration Loads:

Ckt.	Description	Load [Btu/Hr]	% Load of Total			
1	Island Freezer	5,600	21.1%	Cases use	54.9%	of Total Load
2	Reach-In I.C. Case	4,800	18.0%	Freezers use	45.1%	of Total Load
3	Reach-In F.F. Case	4,200	15.8%			
4	8'x8'x8' Walk-In I.C. Freezer	6,000	22.6%			
5	8'x8'x8' Walk-In F.F. Freezer	6,000	22.6%			
	Total	26,600	100%			

CO_2 (R-744) Properties at -20°F:

$P_{saturation}$	=	214.9	[Psia]
	or	200.2	[Psig]
h_{liquid}	=	9.78	[Btu/Lb]
h_{vapor}	=	139.4	[Btu/Lb]
$h_{vaporization}$	=	129.6	[Btu/Lb]
ρ_{liquid}	=	66.86	[Lb/Ft³]
ρ_{vapor}	=	2.41	[Lb/Ft³]
$c_{p,liquid}$	=	0.4975	[Btu/Lb°F]
$c_{p,vapor}$	=	0.2760	[Btu/Lb°F]

Copper Pipe Dimensions:

Pipe Size	Pipe Grade	Flow Area [In²]	Flow Area [Ft²]
3/8" OD	Type L	0.078	0.00054
1/2" OD	Type L	0.145	0.00101
5/8" OD	Type K	0.218	0.00151
7/8" OD	Type K	0.436	0.00303
1-1/8" OD	Type K	0.778	0.00540

Pipe Sizing Calculations:

	Circulation Rate = 1		Circulation Rate = 2		Circulation Rate = 4	
Total System:						
Mass Flow Rate:	205.2	[Lb/Hr]	410.5	[Lb/Hr]	820.9	[Lb/Hr]
Liq. Velocity, 3/8" OD	1.57	[Ft/Sec]	3.15	[Ft/Sec]	6.30	[Ft/Sec]
Liq. Velocity, 1/2" OD	0.85	[Ft/Sec]	1.69	[Ft/Sec]	3.39	[Ft/Sec]
Liq. Velocity, 5/8" OD	0.56	[Ft/Sec]	1.13	[Ft/Sec]	2.25	[Ft/Sec]
Vap. Velocity, 5/8" OD	938	[Ft/Min]	1875	[Ft/Min]	3750	[Ft/Min]
Vap. Velocity, 7/8" OD	469	[Ft/Min]	938	[Ft/Min]	1875	[Ft/Min]
Vap. Velocity, 1-1/8" OD	263	[Ft/Min]	525	[Ft/Min]	1051	[Ft/Min]
Display Cases:						
Mass Flow Rate:	112.6	[Lb/Hr]	225.3	[Lb/Hr]	450.6	[Lb/Hr]
Liq. Velocity, 3/8" OD	0.86	[Ft/Sec]	1.73	[Ft/Sec]	3.46	[Ft/Sec]
Liq. Velocity, 1/2" OD	0.46	[Ft/Sec]	0.93	[Ft/Sec]	1.86	[Ft/Sec]
Liq. Velocity, 5/8" OD	0.31	[Ft/Sec]	0.62	[Ft/Sec]	1.24	[Ft/Sec]
Vap. Velocity, 1/2" OD	774	[Ft/Min]	1547	[Ft/Min]	3095	[Ft/Min]
Vap. Velocity, 5/8" OD	515	[Ft/Min]	1029	[Ft/Min]	2058	[Ft/Min]
Vap. Velocity, 7/8" OD	257	[Ft/Min]	515	[Ft/Min]	1029	[Ft/Min]
Vap. Velocity, 1-1/8" OD	144	[Ft/Min]	288	[Ft/Min]	577	[Ft/Min]

	Circulation Rate = 1		Circulation Rate = 2		Circulation Rate = 4	
Freezers:						
Mass Flow Rate:	92.59	[Lb/Hr]	185.17	[Lb/Hr]	370.34	[Lb/Hr]
Liq. Velocity, 3/8" OD	0.71	[Ft/Sec]	1.42	[Ft/Sec]	2.84	[Ft/Sec]
Liq. Velocity, 1/2" OD	0.38	[Ft/Sec]	0.76	[Ft/Sec]	1.53	[Ft/Sec]
Liq. Velocity, 5/8" OD	0.25	[Ft/Sec]	0.51	[Ft/Sec]	1.02	[Ft/Sec]
Vap. Velocity, 1/2" OD	636	[Ft/Min]	1272	[Ft/Min]	2543	[Ft/Min]
Vap. Velocity, 5/8" OD	423	[Ft/Min]	846	[Ft/Min]	1692	[Ft/Min]
Vap. Velocity, 7/8" OD	211	[Ft/Min]	423	[Ft/Min]	846	[Ft/Min]
Vap. Velocity, 1-1/8" OD	119	[Ft/Min]	237	[Ft/Min]	474	[Ft/Min]

Charge Analysis

CO_2 Properties (at -20°F):

Liquid Density:	66.84 [Lb/Ft³]	Liquid Specific Volume:	0.0150 [Ft³/Lb]
Vapor Density:	2.41 [Lb/Ft³]	Vapor Sepecific Volume:	0.415 [Ft³/Lb]

Display Cases and Walk-Ins:

Circuit		Volume [Ft³]	Liquid Vol.%	Liq. Vol. [Ft³]	Charge [Lbs.]
1A	Island (1/2 case)	0.098	60%	0.059	4.0
1B	Island (1/2 case)	0.098	60%	0.059	4.0
2	Ice Cream	0.282	60%	0.169	11.6
3	Frozen Food	0.282	60%	0.169	11.6
4	8'x8' Ice Cream Freezer	0.109	60%	0.065	4.5
5	8'x8' Frozen Food Freezer	0.109	60%	0.065	4.5
	Totals:	0.977		0.586	**40.1**

Connecting Piping:

Item	Pipe Size	Flow Area [In²]	Length [Ft]	Volume [Ft³]	Liquid Vol.%**	Liq. Vol. [Ft³]	Charge [Lbs.]
Main Supply to Tee	1/2" OD Type L	0.145	75	0.076	100%	0.076	5.0
Tee Supply to Cases	3/8" OD Type L	0.078	80	0.043	100%	0.043	2.9
Tee Supply to Freezers	3/8" OD Type L	0.078	80	0.043	100%	0.043	2.9
Return Cases to Tee	5/8" OD Type K	0.218	80	0.121	4%	0.005	0.6
Return Freezers to Tee	5/8" OD Type K	0.218	80	0.121	4%	0.005	0.6
Main Return from Tee	7/8" OD Type K	0.436	75	0.227	4%	0.009	1.1
Totals:			470	0.631		0.181	**13.2**

**Return Line Liquid Volume % based on Circulation Rate of 2, equal mass of liquid and vapor

Charge Summary:

Coils	40.1 [Lbs.]
Piping	13.2 [Lbs.]
Total Charge	**53.3 [Lbs.]**

ASHRAE-15 Concentrations Calculations

According to ANSI/ASHRAE Standard 15-2001, Table 1:

R-744 (CO_2) is limited to 50,000 ppm or 5.7 Lb/1000Ft^3

Our total system charge is:	60 [Lb]	
At STP, gas density is:	8.8 [Ft^3/Lb]	
Volume if 100% vaporized is:	525 [Ft^3]	

Lab Evaluation by Room:	Room #1	Room #2	Room #3	Room #4
Room Volume:	27,600 [Ft^3]	25,800 [Ft^3]	13,030 [Ft^3]	512 [Ft^3]
Conc. During Total Leak:	1.90 [%]	2.03 [%]	4.03 [%]	102.54 [%]
Conc. In PPM:	19,022 [ppm]	20,349 [ppm]	40,292 [ppm]	1,025,391 [ppm]

Relief Valve Capacity Calculations

<u>Valve Specifications:</u>

Model:	SS-4R3A5-NE
Manufacturer:	Swagelok

<u>R-744 Properties @420 Psig</u>

Saturation Temperature:	22	[°F]
Liquid Density	59.9	[Lb/Ft^3]
Vapor Density	5.11	[Lb/Ft^3]
Liquid Enthalpy:	31.8	[Btu/Lb]
Vapor Enthalpy:	138.0	[Btu/Lb]
Heat of Vaporization:	106.2	[Btu/Lb]

<u>Relief Valve Heat Capacity by Varying Flow Rate:</u>

RELIEF RATE [CFM]	VAPOR FLOWRATE [Ft^3/Hr]	VAPOR MASSFLOW [Lb/Hr]	HEAT FLOW [Btu/Hr]
0.1	6	31	3,258
0.2	12	61	6,516
0.5	30	153	16,289
1	60	307	32,578
2	120	613	65,156

TABLE 2

Carbon Dioxide Secondary Coolant System with Fade-Out Vessel

Refrigerant Properties:

<u>CO_2 (R-744) Properties[1] at -20°F</u>

$P_{saturation}$	=	214.9	[Psia]
	or	200.2	[Psig]
h_{liquid}	=	9.78	[Btu/Lb]
h_{vapor}	=	139.4	[Btu/Lb]
$h_{vaporization}$	=	129.6	[Btu/Lb]
ρ_{liquid}	=	66.86	[Lb/Ft^3]
ρ_{vapor}	=	2.41	[Lb/Ft^3]
$c_{p,liquid}$	=	0.4975	[Btu/Lb°F]
$c_{p,vapor}$	=	0.2760	[Btu/Lb°F]

<u>CO_2 (R-744) Properties[1] at +75°F</u>

$P_{saturation}$	=	909.6	[Psia]
	or	894.9	[Psig]
h_{liquid}	=	67.7	[Btu/Lb]
h_{vapor}	=	122.7	[Btu/Lb]
$h_{vaporization}$	=	55.0	[Btu/Lb]
ρ_{liquid}	=	45.36	[Lb/Ft^3]
ρ_{vapor}	=	14.35	[Lb/Ft^3]
$c_{p,liquid}$	=	1.363	[Btu/Lb°F]
$c_{p,vapor}$	=	1.659	[Btu/Lb°F]

[1] Properties from 2001 ASHRAE Fundamentals Handbook, p. 20.35

System Design:
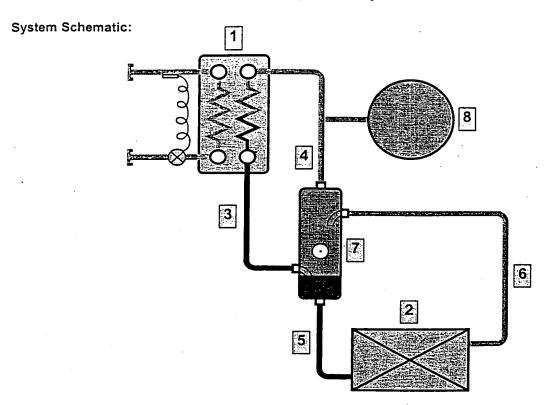
Total Load (Max.)	=	24,000	[Btu/Hr]
or	=	2.0	[Tons Refrigeration]

Assuming Saturated Vapor Entering Condenser, Saturated Liquid Leaving Condenser:

Cond. Mass Flow	=	185	[Lb/Hr]
or	=	3.09	[Lb/Min]
Liquid Volume Flow	=	0.0462	[Ft^3/Min]
or	=	0.00077	[Ft^3/Sec]
Vapor Volume Flow	=	1.28	[Ft^3/Min]
or	=	0.0213	[Ft^3/Sec]

Line Sizing:

PIPE SIZE [OD]	TYPE [L or K]	FLOW AREA[2] [In^2]	LIQUID VELOCITY [Ft/Sec]	LIQUID VELOCITY [Ft/Min]	VAPOR VELOCITY [Ft/Sec]	VAPOR VELOCITY [Ft/Min]	VOLUME [Ft^3/Ft]
3/8"	L	0.078	1.42	85.2	39.4	2364	0.000542
1/2"	L	0.145	0.764	45.8	21.2	1272	0.00101
5/8"	L	0.233	0.475	28.5	13.2	791	0.00162
7/8"	L	0.484	0.229	13.7	6.35	381	0.00336
1-1/8"	K	0.778	0.142	8.54	3.95	237	0.00540
1.5"	Sch. 80	1.77	0.0626	3.76	1.74	104	0.0123
2"	Sch. 80	2.95	0.0376	2.25	1.04	62.5	0.0205
2.5"	Sch. 80	4.24	0.0261	1.57	0.725	43.5	0.0294
3"	Sch. 80	6.60	0.0168	1.01	0.466	27.9	0.0458
4"	Sch. 80	11.5	0.0096	0.58	0.267	16.0	0.0799
6"	Sch. 40	28.9	0.0038	0.23	0.106	6.4	0.2006
8"	Sch. 40	50.0	0.0022	0.13	0.061	3.7	0.3474
10"	Sch. 40	78.9	0.0014	0.08	0.039	2.3	0.5476
12"	Sch. 40	111.9	0.0010	0.06	0.027	1.6	0.7771

[2] Flow Area from 2000 ASHRAE Systems and Equipment Handbook, p. 41.3-4

Carbon Dioxide Secondary Coolant System with Fade-Out Vessel

System Schematic:

Charge Analysis:

<u>Properties @ +75°F, 450 Psig:</u>

Vapor Density, ρ_{vapor}:	= 5.2	[Lb/Ft³]

<u>Properties @ -20°F</u>

Liquid Density, ρ_{liquid}:	= 66.86	[Lb/Ft³]
Vapor Density, ρ_{vapor}:	= 2.41	[Lb/Ft³]
Quality at 5.2 [Lb/Ft³]	= 0.43	(from P-h diagram)

ITEM #	COMPONENT DESCRIPTION	INTERNAL VOLUME [Ft³]		LIQUID CHARGE [Lbs.]
1	Heat Exchanger	0.117		1.96
2	Evaporator	0.109		3.64
3	3/8" Type L Copper Tube, 2' Long	0.0011		0.07
4	5/8" Type L Copper Tube, 2' Long	0.0032		0.00
5	3/8" Type L Copper Tube, 4' Long	0.0022		0.14
6	5/8" Type L Copper Tube, 4' Long	0.0065		0.00
7	Hill PHOENIX Liquid-Vapor Separator	0.0218		0.15
		0.261	Total Liquid R-744 Charge =	5.96

Total System Mass for above liquid mass and system density:	10.46	[Lb]
Required System Volume to hold total charge:	2.01	[Ft³]
Required Volume of Fade-Out Vessel:	1.75	[Ft³]